Hermann D. Schubert

Anatomy of the Orbit 2021

Basic and Clinical Science Course, AAO: Section 2, Chapter 1, pp 5-40, 2015-2016.

Bony Orbit: frontal*, zygomatic, maxillary, ethmoid*, sphenoid*, **lacrimal** and **palatine bone** (7 bones, 3 unpaired*)
Orbital margin is composed of: maxillary, zygomatic, frontal, and lacrimal bone
Lacrimal fossa: anterior crest formed by maxillary bone,
posterior crest formed by lacrimal bone
Orbital roof: sphenoid, frontal bone (trochlea is attached to medial frontal bone)
Medial orbital wall: sphenoid, ethmoid, lacrimal bone and maxilla
Orbital floor: maxilla, zygomatic and palatine bone.
Lateral orbital wall: sphenoid and zygomatic bone
Orbital **measurements**: horizontal 4cm, vertical 3.5cm, depth 4.5cm, volume 30ml
Optic foramen: within sphenoid
transmits: optic nerve, ophthalmic artery, sympathetic fibers
Supraorbital foramen: blood vessels, supraorbital nerve (v)
Infraorbital canal: infraorbital nerve (v)
Zygomatic foramen: zygomatico-facial artery and nerve, zygomatico-temporal artery and nerve
Superior orbital fissure: superior ophthalmic vein, **l**acrimal nerve, **f**rontal nerve, **t**rochlear nerve (**LFT** outside cone), oculomotor nerve (III), nasociliary nerve (V), abducens nerve(VI), sympathetic nerve (inside muscle cone)
Lateral rectus muscle: origin divides supraorbital fissure
Lacrimal artery: single vessel, cranial nerve VI
Inferior orbital fissure: pterigoid nerve, pterigopalatine nerve, inferior ophthalmic vein
Tenon's capsule (fascia bulbi): attaches anteriorly at limbus (underneath palisades of Vogt) and attaches posteriorly to the optic nerve sheath. Specializations are the muscle sheaths, **intermuscular membranes** and the **falciform folds** of Guerin.
Spiral of Tillaux: imaginary line connecting the insertions of rectus muscles, i.e., medial rectus 5.5mm, inferior rectus 6.5mm, lateral rectus 7.0mm, superior rectus 7.7mm.

The ora serrata is found within plus-minus 1mm in approximately 80% of cases.
Oblique Tendon Insertion: **Inferior oblique** has **muscular** insertion temporal and inferior to the geometric posterior pole and covers the inferior rectus. The **superior oblique** has a long (10 + 10mm) **tendinous** insertion, inserts superior and temporal to the posterior pole and is covered by the superior rectus.
Origins of muscles at the **annulus**: levator (also lesser wing) and the 4 rectus muscles.
Origin of the oblique muscles:
the inferior oblique: **maxilla**
the superior oblique: **sphenoid**

The origin of the **lateral rectus muscle** divides the superior orbital fissure (LFT outside cone)
The muscle is supplied by a branch of the lacrimal artery which is a single vessel and it has its own nerve which is the VIth nerve
Conjunctiva: mucus membrane (nonkeratinizing stratified columnar epithelium and lamina propria) divided into limbal, bulbar, forniceal and palpebral.
Eccrine accessory glands produce 10% of secretion:

Krause (associated with fornix, 42 glands in upper, 6-8 in lower fornix)

Wolfring (associated with tarsus, 2-5 in upper, 2 in lower fornix, glands larger)

Lid margins glands:

Zeis: holocrine, sebaceous, associated with hair follicles.

Meibom: holocrine, sebaceous, intratarsal, 20-30 below, 30-40 above.

Moll: apocrine, modified sweat gland

Lacrimal gland: the levator tendon divides the gland into an **orbital** lobe and smaller **palpebral** lobe. 12 excretory ducts pass through palpebral lobe (cave: biopsy). Histology: acinar and myoepithelial cells. Eccrine gland supplied by lacrimal artery.
Innervation of lacrimal gland:

1. Parasympathetic lacrimal nucleus of pons (V)
2. Nervus intermedius sensory root (VII, internal auditory meatus)
3. Passes through geniculate ganglion,
4. greater superficial petrosal nerve (Vidian canal) synapses in sphenopalatine ganglion,
5. ?retroorbital plexus, ?zygomaticotemporal nerve and lacrimal nerve

Excretory system:
Puncta, canaliculi, lacrimal sac, nasal lacrimal duct, inferior meatus, nose
Nasal lacrimal duct: lacrimal fossa to inferior meatus
Fundus of sac: 10mm
Nasal lacrimal duct: 18mm
Inferior meatus: 20mm

Eyelids:
Fissure: 30mm long, 8-11mm wide
Eyelid skin: hairs, sebaceous glands and sweat glands
Tarsus: length 29mm, height upper tarsus 11mm, height lower tarsus 4mm
Orbicularis muscle: orbital portion, palpebral portion, muscle of Riolan which corresponds to **grayline** at lid margin

Cilia: anterior to grayline

Orbicularis (Riolan) **is** the line

Meibomian glands: posterior to grayline,

Tarsal mucocutaneous junction: posterior to grayline, at posterior margin of Meibomian gland orifices.

Levator muscle: Aponeurosis, medial and lateral horn which divides lacrimal gland.

Muller's muscle: attached to tarsus (smooth muscle, interdigitating with striated levator muscle)

Eyelid **vessels**:
Facial system: external carotid
Orbital system: internal carotid
Angular artery: peripheral and marginal arcades
Pretarsal system drains into jugular veins and **posttarsal system** into cavernous sinus.

Cranial Nerves

Basic and Clinical Science Course, AAO: Section 2, Chapter 3, pp.87-109, 2014-2016.
Olfactory nerve: CN I
Optic nerve: **CN II** has the following portions: intraocular 1mm, intraorbital 25mm, intracanalicular 4-10mm, intracranial 10mm. It is similar to the white matter of the brain.
Blood supply of CN II:
Prelaminar: retinal arterioles, part of and at the level of the radial peripapillary net
Laminar: short posterior ciliary arteries (circle of Zinn: SPCA, paraoptic branches, pial arteries)
Orbital: central retinal artery and pial arteries
Intracanalicular: ophthalmic artery
Intracranial: ophthalmic artery and carotid artery

Oculomotor nerve: CN III

Nuclear IIIrd lesion: bilateral ptosis, contralateral superior rectus palsy.
NOTE: There is a single nucleus for both levator muscles. The superior rectus fibers cross in the caudal aspect of the nucleus.
Course of cranial nerve III fascicles: Nuclear complex (located in rostral mid-brain at the level of the superior colliculus)
Red nucleus (Benedict syndrome: ipsilateral IIIrd nerve palsy, contralateral hemitremor)
Cortical spinal tract (Weber syndrome: ipsilateral IIIrd nerve palsy, contralateral hemiparesis
Interpeduncular space
Neighborhood relationships of the cranial nerve III: **posterior cerebral artery**, **superior cerebellar artery**, **posterior communicating artery** (aneurysm at junction with internal carotid), **tentorium cerebelli** (herniation of uncus of temporal lobe across tentorial edge), **cavernous sinus** (syndrome), **superior orbital fissure** (syndrome), **annulus** of Zinn.
Divides into superior and inferior division).
Superior: superior rectus, levator muscles
Inferior: medial, inferior rectus, inferior oblique muscles.
Parasympathetic portion of cranial nerve III: **Edinger Westphal nucleus**, inferior oblique muscle, ciliary ganglion (synapse). Short ciliary nerves: Pupillary sphincter and ciliary muscle.

Pupil, afferent path: visual fibers to **pretectal nuclei** in midbrain. Efferent path: fibers to Edinger-Westphal nucleus. Pupillomotor fibers travel in outer layers of nerve: affected by compression, spared in ischemia.

Ciliary ganglion roots:

1. Nasociliary nerve V (sensory): cornea, iris, ciliary body
2. Oculomotor nerve (parasympathetic): sphincter and accommodation
3. Carotid plexus (sympathetic): dilator and blood vessels

Structures of the cavernous sinus: Internal carotid artery, sympathetic plexus, oculomotor (III), trochlear (IV), ophthalmic maxillary (V), abducens (VI).
IIIrd nerve is closest to internal carotid, abducens nerve courses freely, rest of nerves associated with sinus wall.

Trochlear nerve: CN IV

Features: Nucleus in caudal mesencephalon, level of inferior colliculus, close to 3rd nerve. Crosses completely in anterior medullary velum and exits dorsally, 75mm course around midbrain, superior orbital fissure, outside annulus, innervates superior oblique.

Trigeminal nerve: CN V

Mixed nerve
Sensory: facial sensation
Motor: mastication
Course of trigeminal nerve V: nucleus in pons, divisions converge in Gasserian ganglion which is located in Meckel's cave of temporal bone.
Trigeminal divisions: ophthalmic V 1**, maxillary** V 2, **mandibular** V 3
Spinal (sensory nucleus V): onion skin pattern of facial sensation
Rostral nucleus: midfacial
Caudal nucleus: peripheral face and scalp. Nuclear lesion: concentric perioral hypesthesia. Peripheral lesion: somatotopic hypesthesi a.

Division of ophthalmic V1: **frontal** nerve, **lacrimal** nerve and **naso-ciliary** nerve
Nasociliary nerve: tip of nose(Hutchinson's sign), medial canthus
Long ciliary nerves(2): ciliary body, iris, cornea.
Short ciliary nerves(10): sensation from the globe

Abducens nerve VI: nucleus in lower pons, floor of 4th ventricle (near V, VII, VIII), exits at pontomedullary junction, up clivus, underneath petroclinoid (Grubers) ligament, through Dorello's canal, cavernous sinus courses freely, superior orbital fissure (in muscle cone)

Facial nerve VII: cortical bulbar fibers to facial motor nucleus=upper motor neuron. Upper face: input from both hemispheres, lower face: input from opposite hemispheres. supranuclear lesion: weakness of opposite lower face. Lower motor neuron lesion: hemifacial paralysis.

Parasympathetic VII: lacrimal nucleus V, nervus intermedius VII, greater superficial petrosal nerve, sphenopalatine ganglion, ? retroorbital plexus, ?zygomaticotemporal nerve and lacrimal nerve

Parasympathetic VII: superior salivatory nucleus, nervus intermedius, chorda tympani, submandibular ganglion, submandibular glands, sublingual glands

Sympathetic pathway: posterior hypothalamus (1^{st} neuron), ciliospinal center of Budge C 8, (2^{nd} neuron) paravertebral sympathetic chain, superior cervical ganglion(synapse), internal carotid, cavernous sinus, optic nerve (3^{rd} neuron) Pupil, Mueller's muscle.

Blood supply of the Globe

Basic and Clinical Science Course, AAO, Section 2, Chapter1, pp 36-40, 2015-2016.

The **ophthalmic artery is the first branch of the internal carotid** within the skull and passes through the optic canal into the apex of the muscle cone.
The general course of the ophthalmic artery is:

1. inferior and lateral to the optic nerve in the **canal**, and
2. a **nasal "angle"** above or below the optic nerve, and
3. an **anterior "bend"** to become the supraorbital artery.

3 segments of the ophthalmic artery

1. from origin to angle
2. from **angle to bend**
3. from bend to periphery

The intraorbital course of the ophthalmic artery **from temporal to nasal** dictates a vertical arterial water shed (the 2-3 **main posterior ciliary arteries**) in the choroidal circulation. (The oblique water sheds in the choroid are mostly related to the wheel shaped intraocular entry of the 15-20 **short posterior ciliary arteries**, SPCAS). Occasionally, the central retinal artery and the nasal main posterior ciliary artery have a common origin: **central retinal artery occlusion may therefore be associated with nasal choroidal ischemia**.
The central retinal artery enters the nerve 10-13mm posterior to the globe. It gives off interfascicular and **pial branches** and supplies the retrobulbar nerve.
The **main posterior ciliary arteries** consist of a lateral and medial artery and branch into 15-20 **short posterior ciliary arteries** that surround the optic nerve and together with **paraoptic arteries** (anterior continuation of pial vessels) form the (often incomplete) intrascleral circle of Zinn. The **circle of Zinn** supplies the laminar and prelaminar optic nerve in a segmental fashion and has anastomoses with paraoptic vessels, choroid and pia. Prelaminar optic nerve and peripapillary choroidal circulation are segmental, related to the "distal"= nonparaoptic SPCA.
The **long posterior ciliary arteries** enter the globe obliquely approximately 2.5 mm nasal and 3mm temporal from the optic nerve sheath along the horizontal foveal meridian. Vessels travel anteriorly and obliquely through sclera, then in the

suprachoroidal space and as they reach the supraciliary space, they enter the uvea, branch and form the **major arterial circle of the iris**. The major arterial circle also has recurrent branches to supply the pre-equatorial choroid. Anterior branches supply the iris and the arcades. Apart from the posterior ciliaries, the eye is supplied by muscular branches of the **anterior ciliary arteries** which are paired with each rectus muscle except for the lateral one which has only one artery.
The temporal anterior ciliary artery is a branch of the lacrimal artery, that originates from the first or second segment of the ophthalmic artery. As the anterior ciliary arteries emerge from the muscle, they divide into **episcleral branches** and **major perforating branches**. The perforating branches pierce the sclera to unite with the **major arterial circle of the iris** and to supply the anterior uvea.
The **episcleral branches** give off conjunctival and intrascleral nutrient vessels. The episcleral branches form the perilimbal **superficial marginal plexus**(perilimbal flush in iritis), that gives off the **peripheral corneal arcades**, associated with the **palisades of Vogt**. Recurrent conjunctival vessels supply 3-6 mm of the perilimbal conjunctiva and anastomose with recurrent conjunctival vessels from the fornices.
The venous drainage of the eye is quadrantic through vortex veins and also hemispheric in that the two **superior vortex veins empty into the superior ophthalmic vein** through the supraorbital orbital fissure and the **two inferior vortex veins empty into the inferior ophthalmic vein** through the inferior orbital fissure. The central retinal vein leaves the optic nerve 10mm behind the globe and joins the superior or inferior ophthalmic vein.

OCULAR EMBRYOLOGY 2021

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Good basic texts:
MANN, IC: The Development of the Human Eye. First published 1928. Grune and Stratton, Inc. New York, 1969.
Basic and Clinical Science Course, AAO, Section 2, Chapter 4, pp113-143, 2015- 2016.
Sadler TW: Langman's Medical Embryology. Twelfth edition. Lippincott Williams & Wilkins, Philadelphia 2012.
Embryogenesis=Organogenesis=first 8 weeks, single cell to organ primordia.
Fetal period: 8 weeks to term.
Embryogenesis: female gamete (oocyte) fertilized by male gamete (spermatozoon) forms zygote. Zygote undergoes cleavage, forming 2 -16 blastomeres. The 16 cell stage is reached 4 days after fertilization forming a morula (mulberry). The blastomeres develop a cavity, the blastocyst, which attaches to and implants into the uterine mucosa.
Trophoblast forms placenta. Epi and hypoblast form the three primary germ layers during the phase of **gastrulation** around day 14:
The **embryonic epiblast** forms neuroectoderm, mesoderm and endoderm. The **neural plate** is composed of neuroectoderm and faces the amniotic cavity. The mesoderm is interposed between ectoderm and endoderm. The endoderm faces the yolk sac.
The neural plate shows axial **folds** separated by a **groove** on day 17 after conception parallel to the primitive axial skeleton (notochord) which for the first time gives the embryo a head to tail orientation. The neuroepithelium shows polarity, i.e., the **apex** is up and the cell **base** is down. The neural folds become further elevated until they

fuse to form the **neural tube** on day 22. Tube formation=Neurulation. This **fusion** results in a polar orientation of the neuroepithelium which has the cell apex in and the cell base out.

Organogenesis of the eye: **Optic pits** first appear as evaginations of the forebrain (prosencephalon) on day 23.

The **optic vesicle** is fully developed on day 25 (3 mm stage). In the optic vesicle the cell apices point toward the lumen of the vesicle and the cell bases point to the outside towards the surface ectoderm.

As the **optic cup** forms on day 27 (5-7 mm stage) related to invagination and obliteration of the vesicle cavity an apex to apex arrangement appears at the margin of the cup for the first time.

The **invagination** is eccentric, i.e. it forms the embryonic fissure. The embryonic fissure is required for the hyaloid artery to gain access to the inner eye and for the axons of the ganglion cells to get out of the eye. One might say that as the optic cup moves away from the brain, the axons have to find a short way back to the brain. The **embryonic fissure** closes on day 33 (12-13 mm stage).

The embryonic fissure is located inferonasally and closes at the anterior margin (the future equator of the eye) first. With the closure of the embryonic fissure the basic structure of the eye is established.

Faulty closure results in:

Coloboma

Three facts are required to understand the formation of <u>colobomas:</u>

1) the lips of the optic cup at the embryonic fissure consist of both inner and outer neuroepithelium. One (the inner) is destined to become retina and the other (outer) is destined to become pigment epithelium. If the border of these tissues is not exactly at the margin of the closing fissure and an "eversion" of the inner neuroepithelium exists, then the pigment epithelium is not going to fuse (since laterally displaced) and a pigment epithelial dehiscence will result.

2) The inner neuroepithelium fuses, however it is only the inner neuroblastic layer of the inner neuroepithelium that stays fused and bridges the coloboma.

3) Since choroidal development depends on induction by pigment epithelium, the defect is going to be pigment epithelial **and** choroidal. The outer retina depends on nutrition by both pigment epithelium and choroid. The neuroepithelium bridging such colobomas is going to be more atrophic and gliotic because it has the retinal vascular supply as **only** source of nutrition. As the malformation ages, malnutrition and mechanical stretch set the stage for hole formation in the intercalary membrane and point of reversal and related schisis-like rhegmatogenous retinal detachment

Development of Selected Ocular Tissues:

Neurosensory retina:

4^{th} week: inner marginal and outer primitive neuroectoderm

6^{th} week: inner and outer neuroblastic layer separated by transient layer of Chievitz

6^{th} week: Ganglion cell processes

3^{rd} month: **inner neuroblastic layer** forms ganglion cells, amacrine cells, Muellerian nuclei.

outer neuroblastic layer forms bipolar cells, horizontal cells, nuclei of rods and cones.

Macular development
3-8 months: widening of the layer of Chievitz
6th month: thickening (protrusion) of the fovea
At term: foveal depression, ganglion cells in center form one layer
4 months after birth: lateral displacement of 2nd and 3rd neuron (and Muellerian glia), central increase (crowding) of cones.
Foveal maturation continues for 3-4 years after birth. If it does not, "foveal hypoplasia" may result.

Retinal pigment epithelium*:*
5th week: melanization starts at posterior pole. Complete in one week.

Optic nerve
7th week: hyaloid artery in, axons out of optic cup, through the primitive papilla

Optic Nerve Aplasia
Abnormal development of the primitive papilla. Inner retina thin, no ganglion cells or axons, RPE continuous, no opening in lamina vitrea. The optic nerve sheath attachment may be visible as an outer scleral ring.

Optic Nerve Hypoplasia
Disc "small" <1.5 mm, normal central vessels. Double ring sign. Outer ring: lamina scleralis nervi optici, 3-5mm in diameter. Inner ring: lamina vitrea=RPE= small opening in the optic cup. Can be associated with agenesis of the septum pellucidum and pituitary dysfunction(de Morsier Sydrome)

Megalopapilla
Disc "large">2.25mm, normal central vessels.

Morning glory
Disc large, central glial tuft, cilioretinal vessels at disc margin

Optic Pit (Cavitary Optic Disc Anomaly) is on the spectrum of coloboma
Disc normal size to large. It may be complicated by cavitary optic disc maculopathy, perhaps on the spectrum of peripapillary edema/retinoschisis and pachychoroid syndrome. Defective border layers may be the underlying lesion.

Lens
Derived from surface ectoderm at the 7 mm stage: pit, cup, vesicle.
If separation fails at the 10mm stage or is incomplete it represents Peter's Anomaly

Peter's Anomaly
Lens is adherent to cornea, there is a posterior corneal defect (endothelium, corneal stroma, Bowman's) with termination of Descemet's membrane where the lens is adherent to cornea (Internal ulcer of von Hippel). A central corneal opacity=leukoma, lens stalk and "top hat" lens shape may be present.

Vitreous
Vitreous components, 3-fold origin:
Lens (surface ectoderm), retina (neuroectoderm) and vascular endothelium (mesoderm).
Primary vitreous <6 weeks (<13mm): "Cellular"
Secondary vitreous <8 weeks (13-65mm): "Vascular"
Hyaloid vessels, collagen fibrils (Mueller cell footplates) and hyaluronan added.
Tertiary vitreous at >12 weeks (>65mm): **Zonules** at right angles to **Marginal Bundle of Druault=future vitreous base.**

Persistent Hyperplastic Primary Vitreous (PHPV)
Fetal Vasculature persists anteriorly: **tunica vasculosa lentis**, exaggerated **Mittendorf's dot** and posteriorly: **Cloquet's canal**, **Bergmeister's papilla**. Retinal vascularization may be deficient.
The tertiary vitreous (zonules) does not form properly, therefore the pars plicata does not separate from the lens equator resulting in so called "traction" on or **elongation of the ciliary processes. Microphthalmos and cataract** (lens invasion by vessels or fibrous tissue through a capsular defect) are common findings. **Persistent fetal vasculature (PFV)** is a mild form (forme fruste) of PHPV. Metaplastic cartilage, adipose tissue, smooth muscle, retinal dysplasia and coloboma represent the more severe end of the spectrum.

Developing Bloodvessels
The **dorsal ophthalmic artery** gives off the ventral ophthalmic artery, hyaloid artery, annular vessel and tunica vasculosa lentis. In adulthood, ophthalmic artery**, temporal long posterior ciliary artery** (T) short posterior ciliary arteries and central retinal artery can be traced to the dorsal ophthalmic artery.
The **ventral ophthalmic artery** develops into the **nasal long posterior ciliary artery** (N).
Retinal vascular system: Formation of branch retinal arteries emanating from the papilla at 4 months. Vascularization proceeds from the disc and, where absent, delineates the zone of primary nonperfusion. Completion of retinal vascularization at 8 months.

Uvea
1-2 months: capillary channels, "primitive" choroid=surface vascularization of the CNS.
3 months: choriocapillaris forms from posterior to anterior.
5 months: posteriorly: large, medium, choriocapillaris and anteriorly: medium vessels, choriocapillaris.
Major circle of the iris sends recurrent branches at term.
Uveal melanization 6-7 months: melanization starts at disc, and continues until after birth. (RPE: Melanization 5th week)

Iris
Anterior growth of the neuroepithelium in the third month. The anterior margin of the optic cup is called the " **Marginal sinus of von Szily**". It advances on the posterior surface of the iris stroma to the pupillary margin or seam or ruff. **Pupillary ruff**: Marginal sinus of von Szily reaches pupil in the 4^{th} month and forms the iris sphincter and dilator.
If it fails to do so, partially or completely, the condition is called Aniridia. If the posterior layer grows beyond the pupillary ruff, congenital ectropion may result.

Aniridia
The iris stroma, which preexists and is neural crest derived is variably preserved (iris stromal hypoplasia). The iris pigment epithelium, sphincter and dilator are neuroectodermally derived and are absent. This may be shown on transillumination where no blocking by pigment is noted. The rudimentary bilayer may close the angle, resulting in glaucoma. There is an association with Wilms tumor.

Oculocerebrorenal syndrome of Miller: nonfamilial aniridia, Wilms tumor, microcephaly, genitourinary anomalies.
Neurulation: Is the process whereby the neural plate forms a tube with rostral and caudal openings=neuropores.
Neural Crest Cells: arise from neuroectoderm at the CREST of the neural folds of diencephalic, mesencephalic and rhombencephalic regions (not the forebrain) at the time of tube closure (day 22).
Cells migrate cephalad along the dorsum of the embryo to populate the pharyngeal arches and facial region.

Neuralcrest Migration:
Posterior midbrain, ventral migration: maxillary processes
Hindbrain, rostral migration: frontal nasal processes.
Failure of neural crest to migrate properly into frontonasal, mandibular and maxillary prominences may contribute to midline deformities.

Neuralcrest derived:
corneal stroma,
endothelium,
sclera (except superotemporally),
nerve sheath,
uveal stroma,
uveal melanocytes,
ciliary muscle,
orbital bones,
orbital fat,
muscles,
connective tissue.

Cornea
6 weeks (18mm stage): epithelium and acellular zones separate from lens vesicle (surface ectoderm). If not, **Peter's anomaly** (see above).
Three waves of limbal (neural crest) migration occur, directed to the center of the cornea: endothelium, corneal stroma, iris stroma. Descemets forms anterior banded (1000Angstrom periodicity) layer. If endothelial (Descemets) defect persists related to incomplete separation of lens**: Internal ulcer of von Hippel.**

Sclera:
condenses anterior to posterior and is formed by neural crest except for superotemporally where it is derived from mesoderm.

Mesoderm:
Forms **striated muscle fibers,**
endothelium of blood vessels,
connective tissue superotemporally.

Surface ectoderm:
Forms lacrimal glands,
drainage apparatus,
glands: Moll, Zeis, Meibom,
cilia,
surface epithelium,

corneal epithelium,
conjunctival epithelium,
caruncle,
lids.

Homologues
Retina = brain
Choroid = leptomeninges
Sclera = dura

Derivations:
Retina = neuroectoderm
Choroid = neuralcrest
Sclera = neuralcrest (and mesoderm superotemporally)
Neuroectoderm: iris sphincter and iris dilator.

Ocular development
Optic vesicle: Day 25 (5mm)
Invagination: Day 27 (7mm)
Closure of fetal fissure: Day 33 (13mm)

Age - length (of the embryo) relationships

20 Days	1-4 Somites
30 Days	34-35 Somites
4 Weeks	7 mm
5 "	12 mm
6 "	18 mm
7 "	24 mm
8 "	31 mm
12 "	71 mm
39 "	340 mm

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Basic and Clinical Science Course, AAO, Section 2, Chapter 2, pp 41-85, 2015-2016.

The globe is the home of the retina (part of the embryonic forebrain, i.e. neural ectoderm and neural crest) which it protects, nourishes, moves or holds in proper position.
The retinal ganglion cells (**third neurons** of the visual pathway) have axons that form the optic nerve (a white matter brain tract) and that connect to the lateral geniculate body of the brain (**fourth neurons** of the visual pathway with axons to cerebral cortex).
The **transparent media** of the eye are: tear film, cornea, aqueous, lens, vitreous, internal limiting membrane and inner retina.

Intraocular pressure is the pressure of the aqueous and vitreous compartment. The aqueous compartment is comprised of anterior (200ul) and posterior chamber (60ul).

The anterior chamber is composed of central capsulocorneal and peripheral iridocorneal interspaces. (Both are decreased when chamber flattens). **Aqueous and vitreous compartments** communicate across the anterior cortical gel of the vitreous which seen from up front looks like a donut and is called the **"annular diffusional gap."**

The globe consists of two superimposed spheres, the **corneal radius** measuring 8mm and the **scleral radius** 12mm. The superimposition creates an **external scleral sulcus**, the outflow channels anterior to the scleral spur fill the **internal scleral sulcus**.

Three layers or **ocular coats** are distinguished: the corneal scleral coat, the uvea and neural retina consisting of retina and pigmented epithelium. The coats and components of the inner eye are held in place by intraocular pressure, scleral rigidity and mechanical attachments between the layers. The **corneoscleral coat** consists of cornea, sclera, lamina cribrosa and optic nerve sheath. It is perforated by the major perforating branches of the anterior ciliary arteries, the vortex veins and short and long posterior ciliary arteries.

There are mechanical attachments between lens, vitreous, retina, uvea and choroid. The lens is held in place by the zonular or capsular fibers originating from pars plana and vitreous base: ciliolenticular and orbiculolenticular fibers. The lens is also supported by the anterior cortical gel of the vitreous forming the **ligament of Wieger** at the lens periphery which encircles **Berger's space** in the patellar fossa of the anterior cortical gel.
The **vitreous** itself is held in place by attachments to lens, vitreous base, optic nerve, blood vessels and fovea. The **retina** is attached to the pigmented epithelium at the optic nerve head and ora serrata and diffusely(fascially) to the vitreous fibrils.
The **uvea** has mechanical attachments to sclera at the entry of the long and short posterior ciliary vessels, the **border layer of Jacoby**(choroidal, prelaminar level) at the disc, at the vortex veins and the major perforating branches of the anterior ciliary arteries at the ciliary body level.
The main attachment of the uvea however is at the **scleral spur** where the **longitudinal muscle of Brucke** (tensor choroidalis) inserts.
These attachments determine the configuration of potential choroidal elevations : **shallow anterior**=supraciliary, **quadrilobed**=to vortex insertion, **kissing**=scleral spur to short posterior ciliaries.

The eyeball length is 24mm (21-30mm), the **diameter** is 24mm, the **volume** is 6.5cc and the **weight** is 7.5grams.
The poles of the eye represent the corneal center and (imaginary) scleral center und are connected by the geometric axis. **Meridional planes** (longitudes) pass through the anterior and posterior poles of the eye. Meridional planes may be horizontal (geometric horizontal meridian), vertical or oblique. The foveal horizontal meridan passes through the inferior one half of the optic nerve and through the entry-sites of the long posterior ciliary arteries. The fovea projects midway between optic nerve sheath and entry of the lateral long posterior ciliary artery. The **equatorial plane** (latitudes) lies midway between the anterior and posterior poles and is perpendicular to the meridional plane and

the geometrical axis. The equatorial plane also divides the eye into an anterior and posterior segment.

Distances from the limbus are: pars plicata 1-2mm, ora serrata 8mm, **equator 14mm**, vortex vein ampullae 14-25mm.

Spiral of Tillaux: Imaginary spiral line connecting insertions of recti clockwise in the right eye, counter-clockwise in the left eye.

Distances of rectus insertions from limbus: medial rectus 5.5mm, inferior rectus 6.6-6.9mm, lateral rectus 6.9mm, superior rectus 7.0-7.7mm. The lateral recti insert parallel to the limbus. Superior and inferior rectus insert obliquely, their tendons insert more anterior nasally. Each rectus muscle has two **anterior ciliary artery branches (ACA)** except for the lateral rectus muscle that has only one (lacrimal) artery branch.

Oblique muscles insert posterior and temporal on the globe.
Superior oblique: "tendinous" insertion and "covers" superior rectus. The tendon measures 10mm to the **trochlea that is attached to the nasal frontal bone**. There is also a 10mm tendon to the belly of the superior oblique muscle originating from the sphenoid bone.
Inferior oblique: "muscular" insertion and "covers" inferior rectus. The muscle measures 40mm in length=shortest muscle. Fascia to inferior rectus and orbital ligaments to medial and lateral rectus form a hammock **(suspensory ligament of Lockwood)**
Inferior oblique muscule inserts temporally on the foveal horizontal meridian on posterior sclera="submacular". (Does not originate from annulus. Origin: maxilla).
Horizontal macular folds: related to horizontal inferior oblique insertion in **hypotony** combined with thin sclera.
Vortex veins: 4-7 in number, usually 4mm posterior to the equator but also at the equator. Each quadrant has at least one vortex vein. Vortices empty into the superior and inferior orbital vein with respective orbital fissure and into **cavernous sinus**. Cave: postseptal cellulitis=intraorbital inflammation that may extend into cavernous sinus.

Cornea: Measurement 12mm horizontally, 11mm vertically, thickness 0.7mm at periphery and 0.5mm centrally

Corneal layers: nonkeratinizing stratified squamous epithelium, 5-6 cell layers: surface cells, wing cells and basal cells. Bowman's layer is a condensation of anuclear anterior stroma, that is PAS negative and corresponds to papillary dermis. Stroma makes up 90% of corneal thickness, the anterior one third corresponds to reticular dermis and is more cohesive than posterior or predescemets stroma that consists of 5-8 hypocellular lamellae and mostly type 1 collagenous bundles. The posterior stroma corresponds to subcutaneous tissue.
Predescemet posterior stromal layer defined by big bubble technique in DALK, it is intrastromal and smaller in diameter(type1) than predescemet separation.

The deepest lamellae of stroma are "infiltrated" by Descemet. Fibrils criss-cross at 90 degree angles. Collagen I,III,V,VI. **Descemet's membrane**: thickness 3 -12 microns, **anterior banded zone**, posterior non-banded zone. Rich in type IV collagen. The DMEK scroll will have endothelium on the convex outside. Endothelium composed of hexagonal cells with serrated margins. The intercellular junctions project into anterior chamber. Electroosomotic transport.
Scleral thickness anteriorly 0.6mm, at the insertions of rectus muscles 0.3mm, at equator 0.5mm, and at posterior pole 1.0mm. Sclera proper has criss-crossing collagen, elastic fibers and openings for blood vessels. It is covered externally by episclera, including **episcleral vessels** and their anterior and posterior plexus and internally by pigmented **lamina fusca**, both important for "perpendicular" healing.

The Limbus

Clinicians's limbus: Transition of clear cornea to opaque sclera (corneo-limbal junction)
Histologist's limbus: transition of regular corneal stromal lamellae to irregular scleral stromal lamella. (peripherally convex line)
Pathologist's limbus: tissue roughly between external and internal scleral sulcus, 1-2mm wide. Internal scleral sulcus bordered by end of Decemet's membrane (corneo-limbal junction) and scleral spur (limbo-scleral junction)
Central margin: **(corneo-limbal)** line through end of Bowman's (superficial) and Descemet's membrane(deep)
Peripheral margin: **(limbo-scleral)** line through scleral spur (deep) perpendicular to outer sclera.
Angle components: inner scleral sulcus, scleral spur, **arciform boundary**. Note: chamber "angle" is posterior and peripheral to trabecular meshwork.
Spatial zones of the anterior chamber: central capsulocorneal interspace, peripheral iridocorneal interspace.
Trabecular meshwork: uveal, corneoscleral meshwork, juxtacanalicular tissue and Schlemm's canal
Conventional outflow: trabecular meshwork
Nonconventional outflow: stroma of the anterior ciliary body
Conventional outflow of aqueous: anterior chamber, uveal meshwork, corneoscleral meshwork, juxtacanalicular tissue, sinus venosus (canal of **Schlemm)**, collector channels (of **Sondermann**), aqueous veins (of **Ascher**), episcleral veins
Uvea: iris, ciliary body, choroid
Uveal borders: iris root, ora serrata, border tissue of Elschnig
Uveal attachments: scleral spur, major perforating branches of anterior ciliary arteries, vortex veins, posterior ciliary vessels, optic nerve
Note difference in anterior point of attachment: Uveal effusion = scleral spur. Retinal detachment = ora serrata. The posterior attachment points for both are the optic nerve axons.
Iris: Central **pupillary portion** and peripheral **ciliary portion** of the iris stroma are divided by **collarette**. The collagen is organized as bands or trabeculae, separated at the collarette by Fuchs crypts and peripheral ciliary crypts. The ciliary portion is attached to

ciliary body at the iris root. Depending on dilation circular contraction folds are seen in the ciliary portion. Rupture of iris root: irido-dialysis.
Iris layers anterior-posteriorly: anterior border layer, stroma, blood vessels, bilayered neuroepithelium.
No epithelium covers the anterior iris surface. Anterior border layer is composed of fibroblasts and melanocytes. Both iris sphincter and dilator are neuro-ectodermal (optic cup) derivations. The posterior iris surface shows central radial contraction furrows and the peripheral structural folds of Schwalbe. Sphincter and dilator are attached to each other at the **central Fuchs' spur** and **peripheral Michael's spurs**.

Peripheral iris and ciliary sulcus epithelium have the densest pigmentation. (sulcus fixation of IOL = iatrogenic depigmentation)

Iris dilator: sympathetic. Hypothalamus, synapse C8, superior cervical ganglion, carotid, long posterior ciliary nerves.
Iris sphincter: parasympathetic. Edinger-Westphal nucleus, oculomotor nerve, cavernous sinus, inferior oblique, **synapse ciliary ganglion**, short ciliary nerves.
The iris epithelium is a bilayer: apex to apex The anterior layer has myoepithelial-like (dilator) differentiation. The posterior layer is more densely pigmented.
Spatial zones of the posterior chamber: **iridocapsular interspace** (cave: affected be posterior synechiae), **iridozonular interspace**(narrowed in pigment-dispersion), **ciliocapsular interspace**, **hyaloideocapsular interspace**(Petit)

Ciliary body: As part of uvea the components are epithelium and stroma (including ciliary muscle)
Pars plicata: major and minor processes. There are 60-70 ciliary processes. Pars plicata (corona ciliaris) is found at 1mm posterior to the limbus and measures 2mm anteroposteriorly.
Pars plana: ora bays and dentate processes (of the retina) The pars plana (orbiculus ciliaris) measures 4mm anterior-posteriorly
The **ciliary muscle**: longitudinal muscle **(Brucke's muscle=tensor choroidalis)** oblique and circumferential muscle fibers.

Choroidal thickness: at optic nerve 0.25mm at ora serrata 0.1mm, depending on age, refractive error, intraocular pressure.
Choroidal layers: Bruch's membrane, choriocapillaris, subcapillary fibrous tissue, medium vessels(Sattler's layer), large vessels (Haller's layer), lymphatics and nerves.
Vascular pigmented sandwich: RPE pigment, vessels, outer choroidal pigment.
Fibrous structure of the choriocapillaris: Bruch's membrane, intercapillary bridges, subcapillary fibrous tissue.
Choroid: choriocapillaris, slits, medium and large vessels.
Choriocapillaris: "choroidocapillaris", lobules, precapillary arterioles, postcapillary venules.
Bruch's membrane: basal lamina of the RPE, collagenous layer (thick), elastic tissue, collagenous layer (thin), basal lamina of choriocapillaris, intercapillary bridges.

Lens: diameter: 10mm, lens epithelium, nuclear bow, lens sutures and lens zonules. The lens capsule measures between 24 – 4 microns. (4 microns centrally where you polish.) The lens fibers are 14mm long. **Lens zonules** (capsular fibers) can be divided into **cilioanterior, cilioequatorial and cilioposterior**. The **orbiculoanterior** and **orbiculo posterior** fibers originate from the dentate processes of the retina, form the **orbiculohyaloidal interspace of Hannover**, rest on the anterior hyaloid and "suspend" the anterior vitreous.
Spatial zones of the lens: **lenticular space**(which one opens by capsulorrhexis and where one sculpts), **capsulocorneal interspace**(where one phacos in the AC).

Apex to apex arrangement of the optic cup: Apex in, basement membrane out
Subretinal space: potential space between retina – RPE(epithelio-retinal interspace)
Subretinal space borders: border tissue of Kuhnt (**posterior cul-de-sac**) – ora serrata (**anterior cul-de-sac**)
Suprachoroidal space: potential space between choroid-sclera. Anteriorly it is called supraciliary space.
Suprachoroidal space borders**: border tissue of Elschnig** (posterior cul-de-sac) – **scleral spur** (anterior cul-de-sac)
Homology: retina-brain, choroid-leptomeninges, sclera-dura

Neurosensory retinal layers: internal limiting membrane, nerve fiber layer, ganglion cell layer (third neuron), inner plexiform layer, inner nuclear layer=bipolar layer(second neuron), outer plexiform layer, outer nuclear layer, external limiting membrane, rods and cones.

Simplified layer anatomy of the retina:

First, remember that the outer nuclear layer(receptor layer) consists of **rods and cones**. Second, remember that the **nerve fiber layer and ganglion cell layer** consists of ganglion cells and their axons.

Thirdly, CONCENTRATE ON THE INNER NUCLEAR LAYER because it contains bipolar cells and is therefore called **"bipolar layer"(** second neuron)**.** The inner nuclear layer also houses the Muellerian cell body that is the structural backbone of the retina. On the inside of the bipolar cell layer are located the **amacrine cells** for horizontal connections. On the outside of the bipolar cell layer are the **horizontal cells** also for horizontal connections.The intermediate capillary plexus is at the level of the amacrine cells, the deep capillary plexus is at the level of the horizontal cells. PAMM=Paracentral Acute Middle Maculopathy is related to ischemia of the inner nuclear layer (INL). Furthermore, **plexiform layers (outer and inner)** are found on either side of the inner nuclear (bipolar) layer.

From the above follows:
The bipolar cell processes and inner amacrine processes connect to the ganglion cell processes in the **inner plexiform layer**.

The horizontal cells which are located on the external side of the inner nuclear layer and the bipolar cell processes will connect to rod-sperules and cone-pedicles in the **outer plexiform layer**.
The outer plexiform layer is somewhat divided in that only the inner third is truly plexiform. The inner 1/3 is separated from the outer 2/3rds by the **middle limiting membrane** that is composed of synapses and their junctional systems connecting the axons of rods and cones (inner fibers of Henle) to the inner nuclear layer neurons. The middle limiting membrane denotes the limit of retinal capillaries as well as a barrier to exudates.
Highly reflective on OCT imaging are: nerve fiber layer, middle limiting membrane, external limiting membrane, ellipsoid zone, mitochondria of RPE.
The four outer lines on OCT are: external limiting membrane, ellipsoid zone, interdigitation zone, pigment-epithelium.

Radial glia of Mueller cells: Mueller cell nuclei are located in the inner nuclear (bipolar) layer. The cells are invested by a rich intermediate and deep capillary plexus and suffer in retinal vascular disease (CRAO, Sickle, Diabetes). Mueller cells elaborate the internal limiting membrane that is their cell base (base in, apex out). The Mueller cell apex points to the photoreceptors and is part of the external limiting membrane, a desmosomal junctional system. The apical processes of Mueller cells communicate with the apical villous processes of pigment epithelial cells across the interphotoreceptor matrix (apex to apex, interdigitation zone) and guarantee the well being of both photoreceptors and neurons.

Retinal bloodvessels: branch arteries, radial peripapillary net, intermediate capillary plexus, deep capillary plexus, radicular vessels.

Blood supply of retina: Capillaries derived from the central retinal artery supply the Muellerian glia, bipolars, and the entire inner nuclear layer, specifically: 1)superficial, radial capillaries supply nerve fibers, 2)intermediate capillaries supply amacrine cells, 3)deep capillaries supply horizontal cells. Outer (photoreceptor) layers are supplied by choriocapillaris. . 80% of the retinal nutrition comes from the choroid.

Macular blood supply: temporal short and long posterior ciliary vessels, including a "macular artery"
Central retinal artery loses internal elastic lamina near disc. The wall has smooth muscle layers, 5-7 at disc, 2-3 at equator, 1-2 peripherally.

Macula: (Central area) Histologically more than one ganglion cell layer, about one half of all ganglion cells of the retina are in the central area, topographically between disc and major temporal arcades (5.5mm diameter)
Umbo: center (navel)**. Foveola** 0.3mm**, Fovea** 1.5mm diameter, **Parafovea** 0.5mm belt, **Perifovea** 1.5mm belt
Foveola: Only cones and elongated Mueller cell processes (other neurons and glia are laterally displaced). The foveola represents the **bottom** of the fovea, is nourished by

choroid , is 0.13mm thin and is rod-free=cone-only. Also known as "nuclear cake"(Rochon-Duvigneaud).
Foveal avascular zone: 250-600 micrometers diameter
Foveal margin: periphery of foveal declivity, margin 0.25mm thick,
Fovea: 1.5-2 mm distance from margin to margin (foveal diameter)

Peripheral retina: (extra areal retina):

Belt of near periphery	1.5mm wide.
Belt of middle periphery(equator)	3.0mm wide
Belt of far periphery	10-16mm wide

Extreme periphery corresponds to the ora serrata
Wide Field Imaging:
Posterior pole to the vascular arcades, 60 degrees
Mid periphery, arcades to vortex vein ampullae, 60-110 degrees
Far periphery, anterior to vortex vein ampullae
Retinal thickness:
At optic nerve - 0.23 mm
At ora serrata - 0.11mm

Ora Serrata: (extreme periphery) border between nonpigmented epithelium and peripheral retina. Also border of Mueller cell presence and ring of vitreous attachment(base), two-four mm wide. The Mueller cell apices connect to the apical non-pigmented epithelial cells. Dentate processes of the retina are more prominent nasally. Cystoid degeneration is more prominent temporally (Blessig-Ivanoff cysts)

Optic Nerve: 50mm in length overall,

intracranial	10mm
intracanulicular	6mm
intraorbital	33mm
intraocular	0.7mm

diameter at scleral canal - 1.5mm
posterior to globe, the diameter is 3.4mm related to myelination of axons by oligodendroglia.

Meninges surround disc posterior to globe. Dura connects to sclera, leptomeninges to choroid. The **border layer of Kuhnt** is at the level of the retina and the **border layer of Elschnig(fibrous, temporal)** and the border layer of **Jacoby(glial)** at the choroidal level
General principle: Border tissues are glial tissues that separate retinal pigment epithelium and axons from choroid and sclera

The optic nerve rim is also characterized by the termination of Muller cells. Anteriorly, Mueller cells terminate at ora serrata, where the external limiting membrane unites with RPE cell apices. Posteriorly Mueller cells terminate at disc, external limiting membrane unites with RPE cell apices, the ILM becomes the membrane of Elschnig, elaborated by astrocytes. Both cover the area of Martegiani on the disc, and, if detached, contribute to the glial **Weiss Ring** in posterior vitreous detachment.

Where Muller cells end, the BM thickness changes, associated with strong vitreous attachments: vitreous base, peripapillary ring

Vitreous: two macromolecules, collagen (mostly type 2) and hyaluronan
Aqueous-Vitreous Compartments
Intraocular spaces: extrahyaloid, intrahyaloid.
Vitreous **attachments**: lens: ligament of Wieger, vitreous base, retinal vessels, perifovea: "peephole", optic nerve, glia of area of Martegiani.
Ligamentum Hyaloideocapsulare of Wieger: peripheral boundary of Berger's space, insertion of cilioposterior fibers, tractus hyaloideus,.
Spatium retrolentalis Berger: potential space between posterior lens capsule and patellar fossa=anterior cortical gel. Nd:Yag capsulotomy is likely to open Berger's space.
Canal of Petit: Space between posterior zonules and anterior cortical gel. May contain pigment, blood, air.
Orbiculohyaloidal Space of Hannover: between anterior and posterior zonules.
Cloquet's Canal: posterior to central cortical gel, funnel to area of Martegiani.
Area of Martegiani: circular vitreous cortical defect and vitreous attachment to optic nerve=papilla

ANATOMY SHOULD KEEP PACE….